Experimental Characterization of Gas/Gas Injector Flowfields

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JANNAF Meeting - 2002
April 8-12, 2002
Destin, Florida

OUTLINE

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- Approach
- Rocket Setup
  - Fuel & Oxidizer Preburners
  - Shear Coaxial Injector
  - Rocketdyne Injector
- Experimental Setup
  - Flow Conditions
  - Raman Setup
- Measurements
  - Fuel & Oxidizer Preburner Characterization
  - Raman Measurements to Date
- Summary

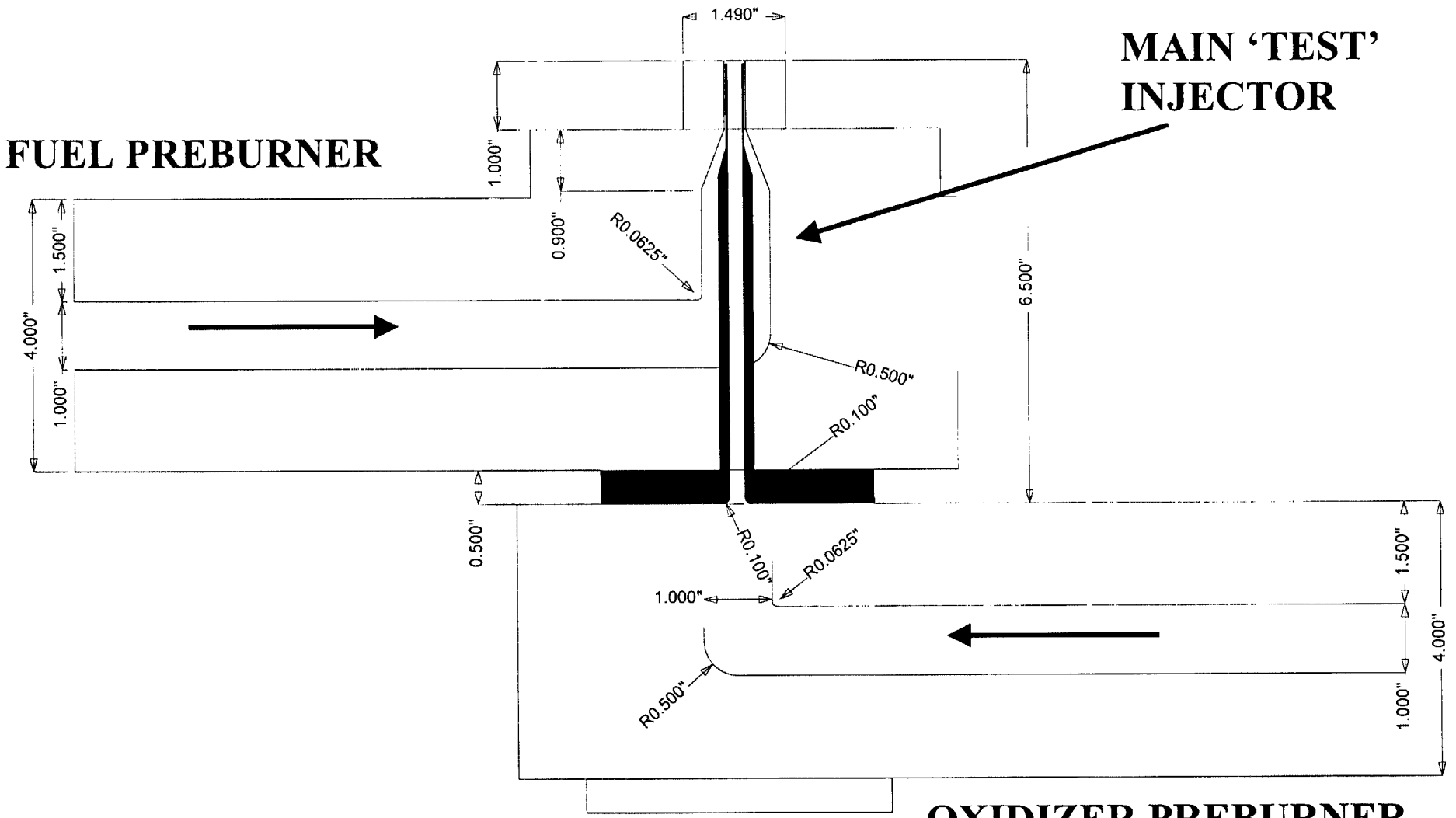
OBJECTIVES

- **Study Flowfield Characteristics of Gas/Gas Injectors**
- **Provide Experimental Data to Aid CFD Modeling at NASA Marshall Space Flight Center (MSFC)**

APPROACH

- **Design/Fabricate Optically-Accessible Rocket Chamber for Uni-element Flowfield Characterization Utilizing Laser-based Diagnostic Techniques**
- **Fuel and Oxidizer Preburners Provide Realistic Hot-gas Operating Conditions Based On Full-scale Conditions For a Full-flow Engine Cycle**

FUEL AND OXIDIZER PREBURNERS

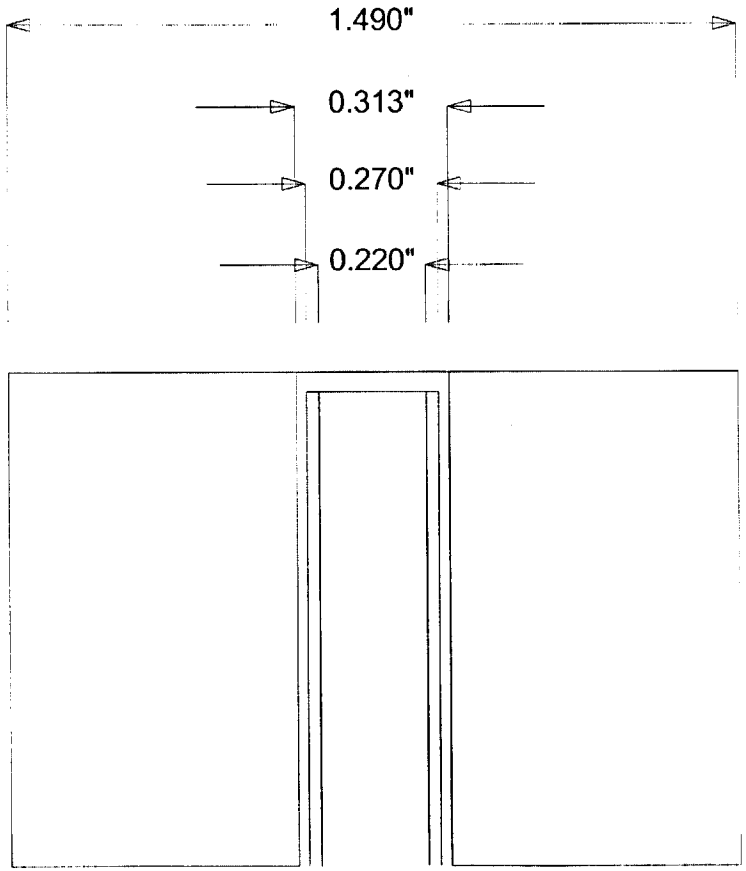


FUEL & OXIDIZER PREBURNER DESIGN

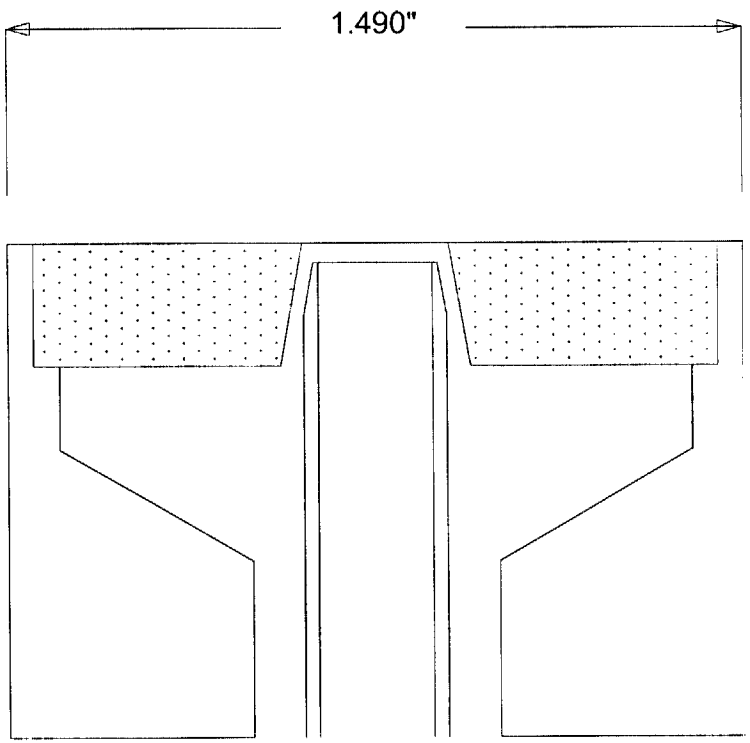
- Preburners Designed to Integrate Directly With Study Injector and Main Chamber
- Each Preburner Has Two Injection Stages:
  - Main O_2/H_2 Impinging Injector For 'Hot Core"
  - Downstream Dilution Injectors
- Oxidizer and Fuel Preburners Made With Monel and OFHC Copper, Respectively
- O_2/H_2 Torch Ignitor For Each Preburner

GAS-GAS INJECTORS

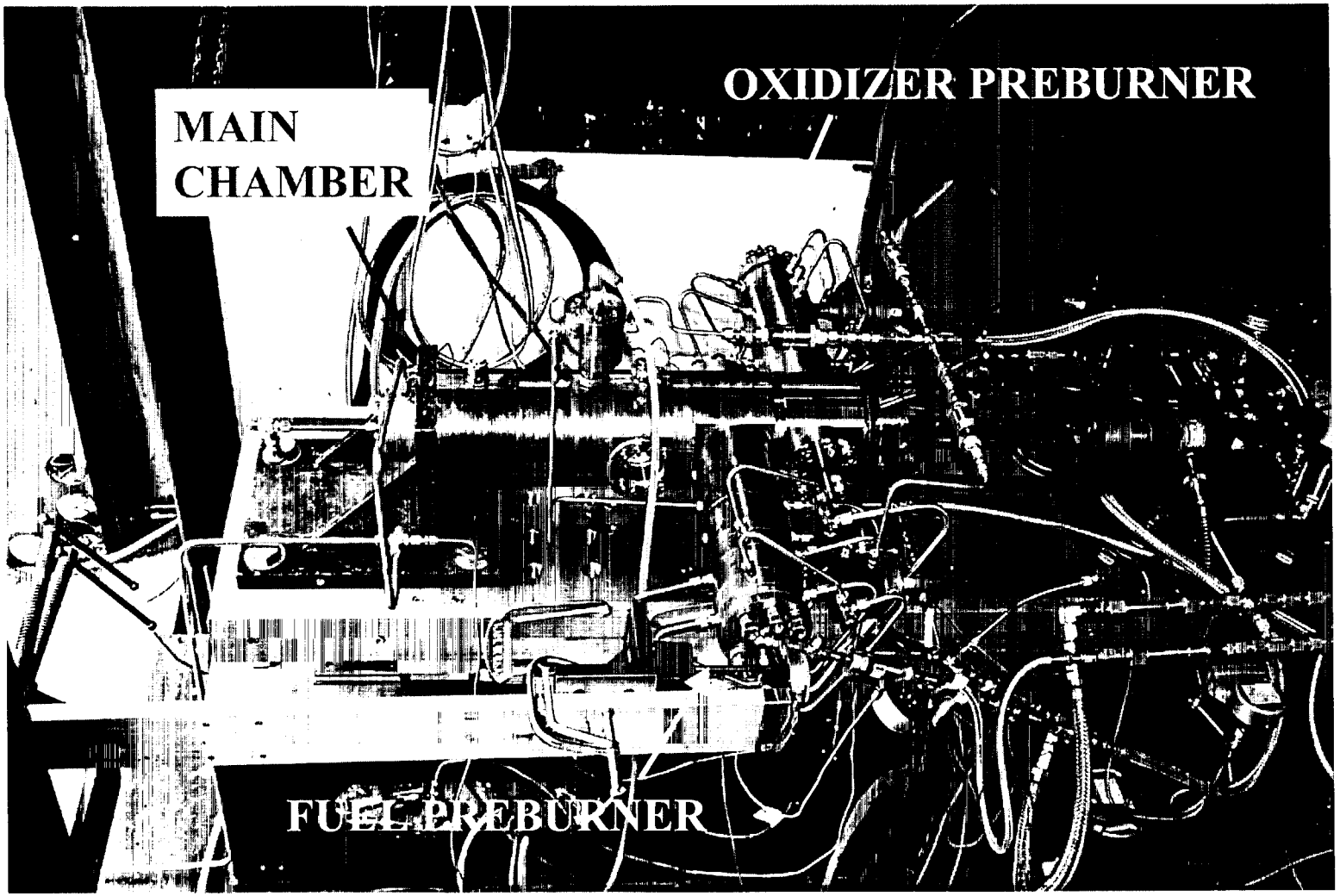
SHEAR COAXIAL INJECTOR



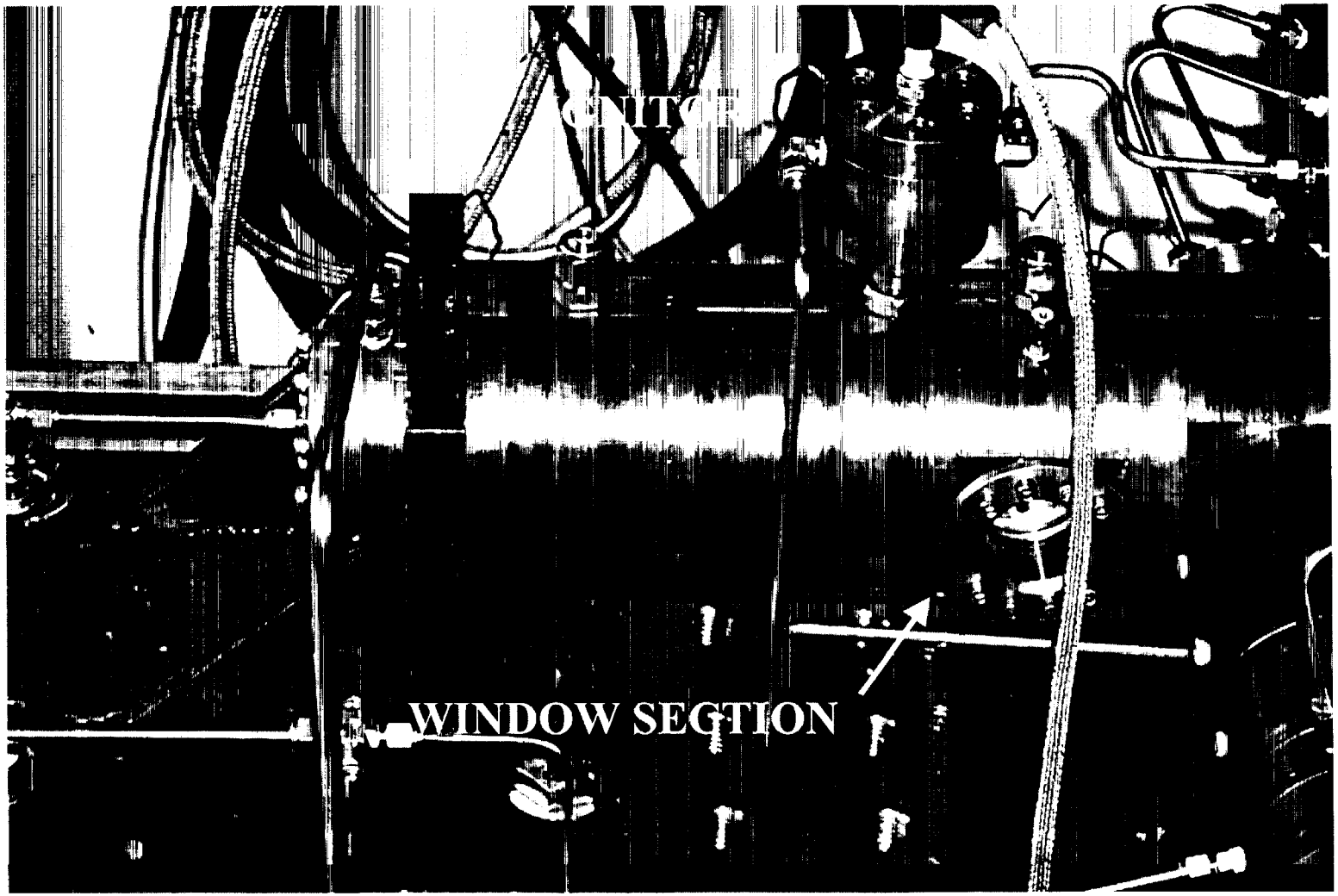
ROCKETDYNE INJECTOR
THE BOEING COMPANY
US PATENT NO. 6,253,539



ROCKET SETUP



MAIN ROCKETCHAMBER



MAIN CHAMBER DESIGN

- Heat-sink Design Main Chamber Fabricated with OFHC Copper With 1.5 in. Diameter Internal Cross-section
- Main Chamber Designed for 1000 psia Operation
- Optical Access Provided By Quartz Window
- Modular Design Allows Easy Configuration Changes for Optical Measurements in 0.5 in. Axial Increments
- Water-cooled Nozzle For O_2/H_2 Operation At Near Stoichiometric Conditions (~ 6500 R)

TARGET FLOW CONDITIONS

	Full Scale Design	Uni-element Experiment*
Preburner Propellants	LOX/GH_2	GO_2/GH_2
Main Chamber Pressure (psia)	3000	750
# of Injection Elements	91	1
Injector Element Geometry	FULL-SCALE	FULL-SCALE
Total flowrate per Element (lbm/s)	1.178	0.295
Ox. Preburner O/F	165	GO_2/GH_2 and H_2O**
Ox. Preburner Temperature (°F)	~700	~700
Fuel Preburner O/F	0.45	0.45
Fuel Preburner Temperature (°F)	~900	~900
Injection Velocity	*SAME*	*SAME*
Ox. Preburner/Fuel Preburner Flowrate Ratio	4.0	4.0
Total O_2/Total H_2	6.0	6.0

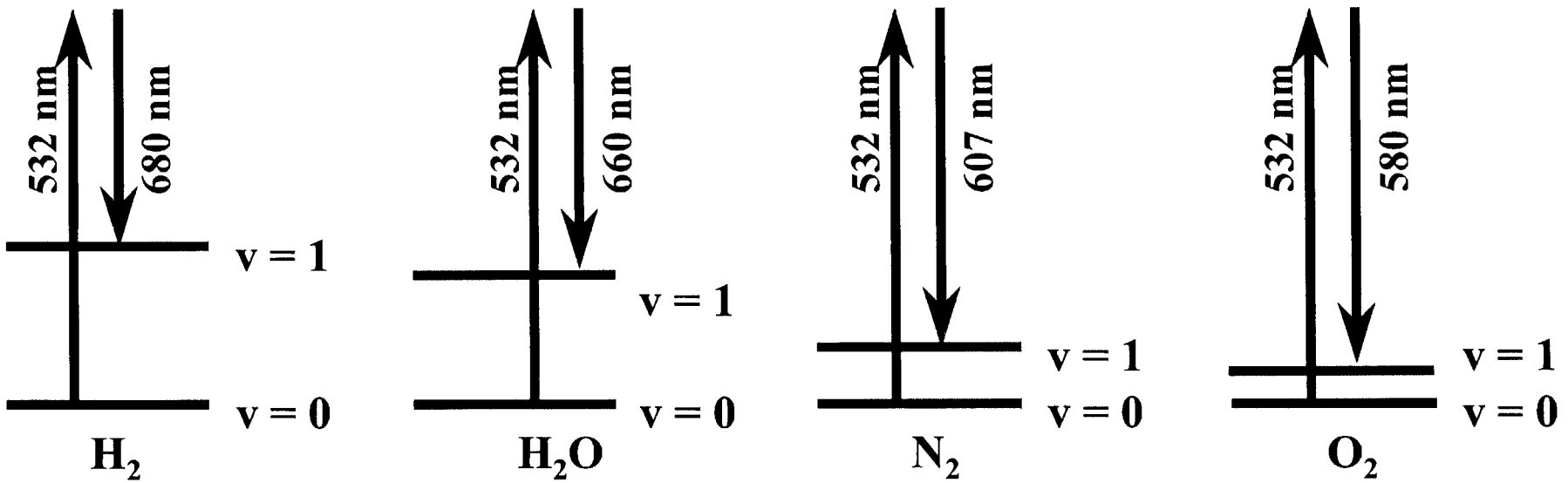
** ¼ Pressure Condition*

*** Propellants Yield Correct Temperature and Species as Full-scale*

RAMAN SPECTROSCOPY

- Used to Determine Major Species Concentrations Downstream of the Rocket Injector
- Modular Rocket Design Allows Optical Access to Be Moved to Various Locations
- ICCD Camera With Bandpass Filters Allows O_2, H_2, and H_2O Measurements With One Species Per Rocket Firing

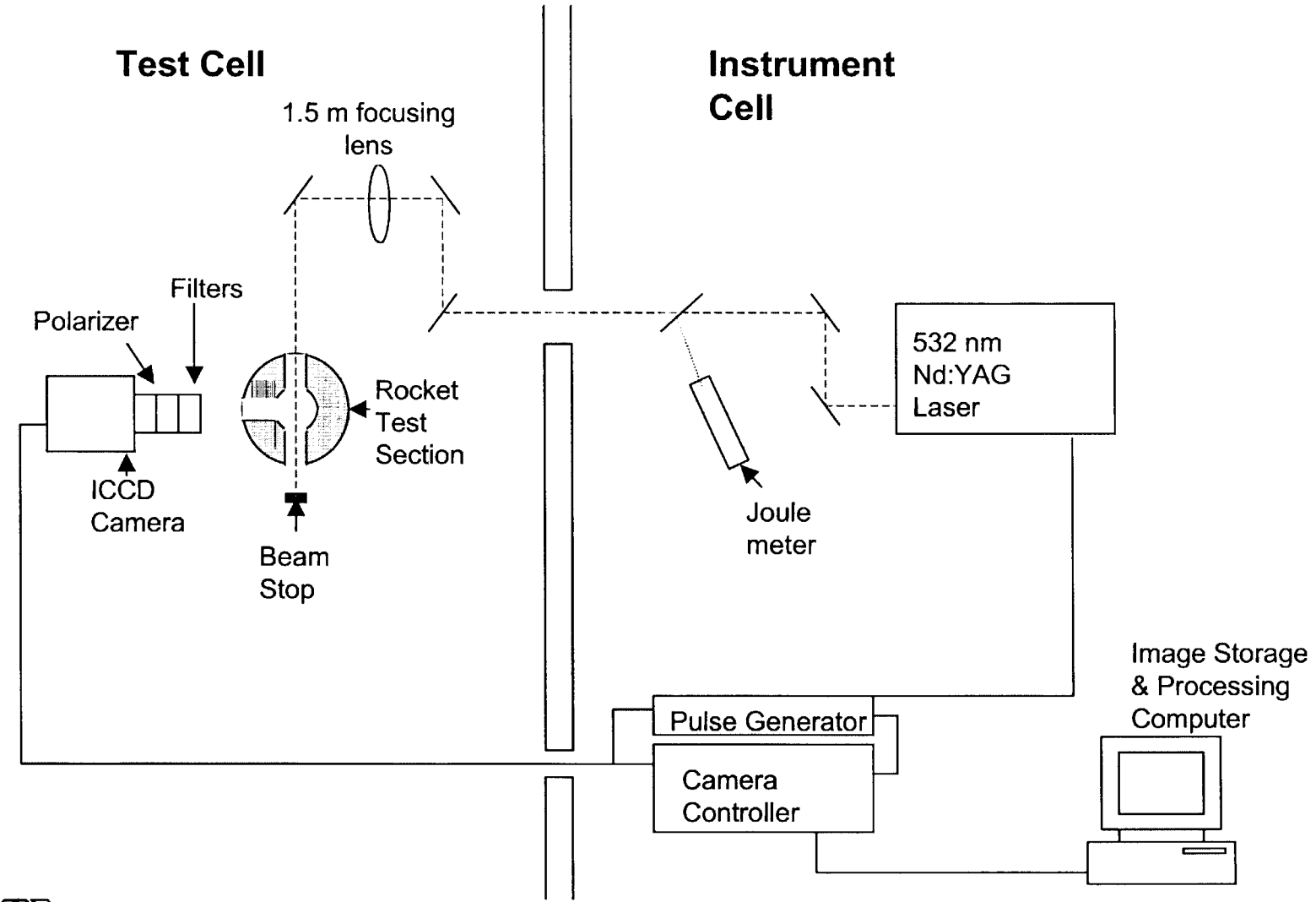
RAMAN SPECTROSCOPY



- Raman Signal Specific to Each Species
- Linearly Proportional to Species Number Density

RAMAN SPECTROSCOPY SETUP

(FILTER APPROACH)

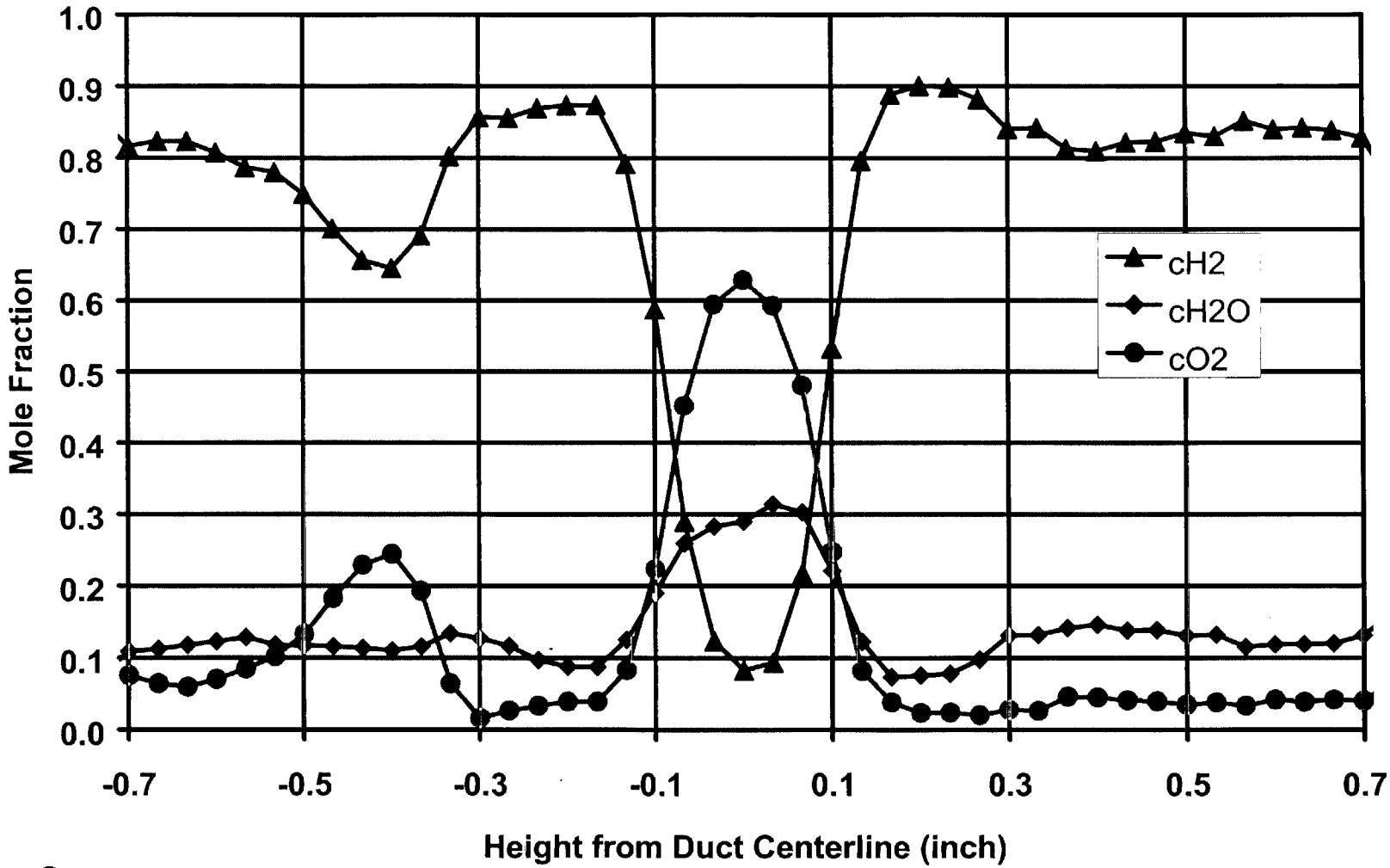


RAMAN FILTERS

• O_2 Filter:	Center Wavelength:	581nm
	Bandwidth:	10 nm
• H_2O Filter:	Center Wavelength:	662 nm
	Bandwidth:	10 nm
• H_2 Filter:	Center Wavelength:	682 nm
	Bandwidth:	10 nm

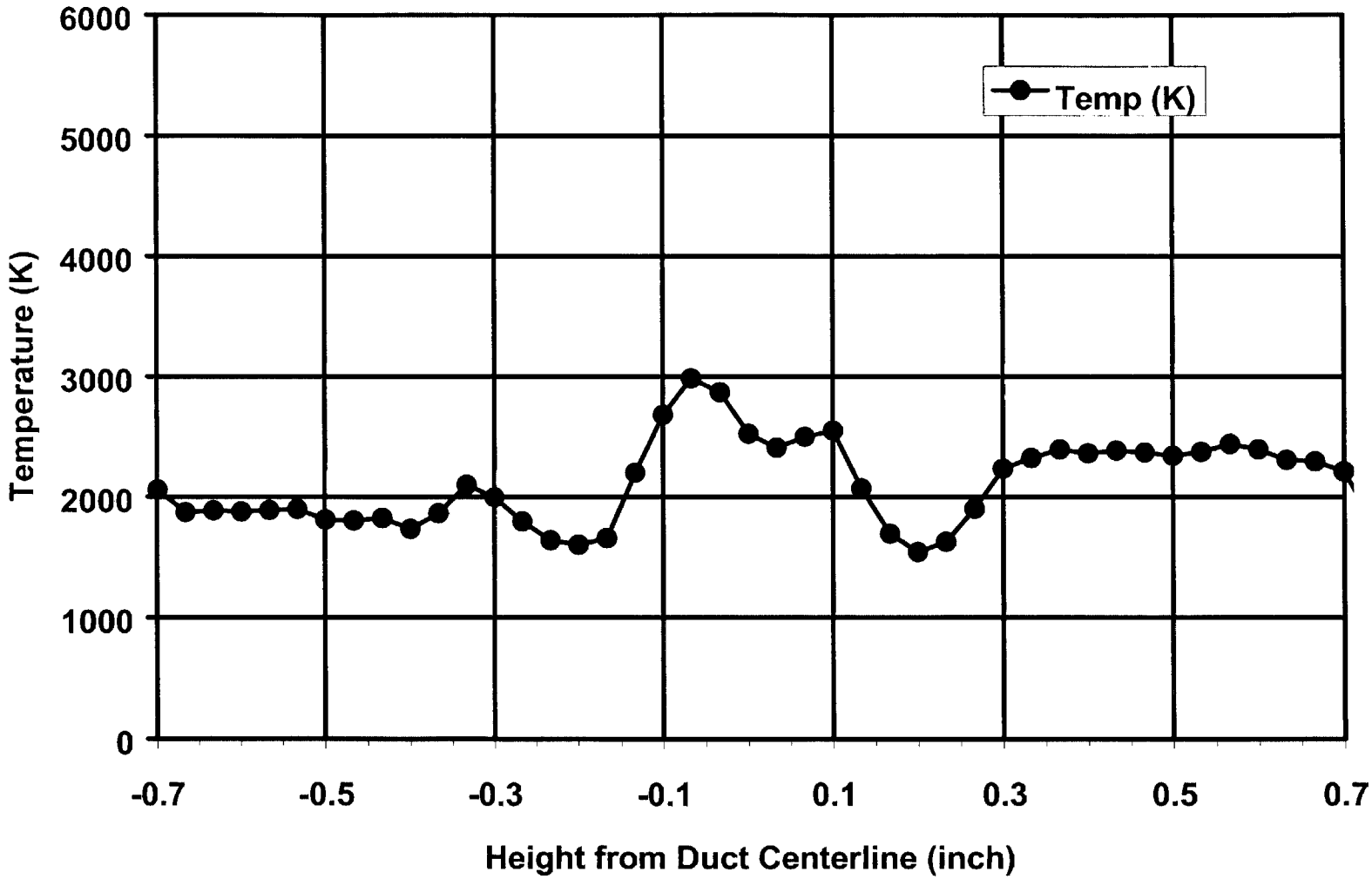
SPECIES MEASUREMENTS

(ROCKETDYNE INJECTOR; 0.5 in. AXIAL DISTANCE)



TEMPERATURE PROFILE

(ROCKETDYNE INJECTOR; 0.5 in. AXIAL DISTANCE)



SUMARY OF INITIAL EXPERIMENTS

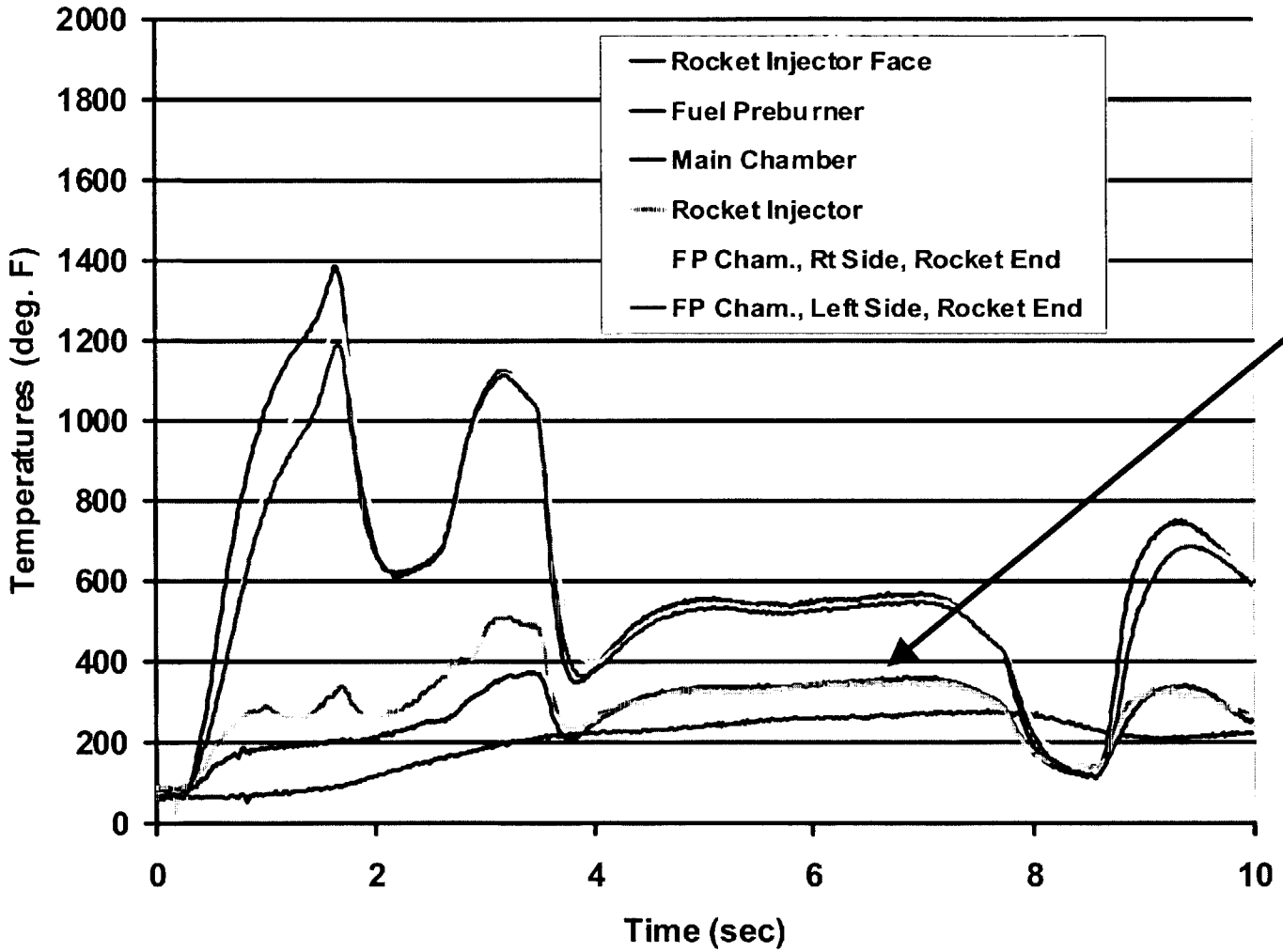
- Raman Spectroscopy With Filter Approach Prevented Discrimination of H_2 Rotational Line From O_2 Vibrational Line
- Significant Heat Loss in Preburners Resulted in Lower Temperature Gases Exiting From Both Preburners
- Decision to Run Fuel Preburner at Higher O/F to Obtain Correct Gas Temperature
- Decision to Run Oxidizer Preburner at O/F=165 (GO_2/GH_2) To Hopefully Yield Correct Gas Temperature

PREBURNER TEMPERATURE EXPERIMENTS

- Operated Each Preburner Individually To Assess Hot Gas Temperature
- Thermocouples Mounted at Various Locations Within Preburner Provided Hot Gas Temperatures
- For Fuel Preburner, O/F Was Progessively Increased to Yield Correct Exit Gas Temperature (~ 900 F)
- For Oxidizer Preburner, Only GO_2/GH_2 Propellants Were Used at O/F=165 Since GO_2/GH_2 Runs Hotter Than LOX/GH_2

FUEL PREBURNER ONLY

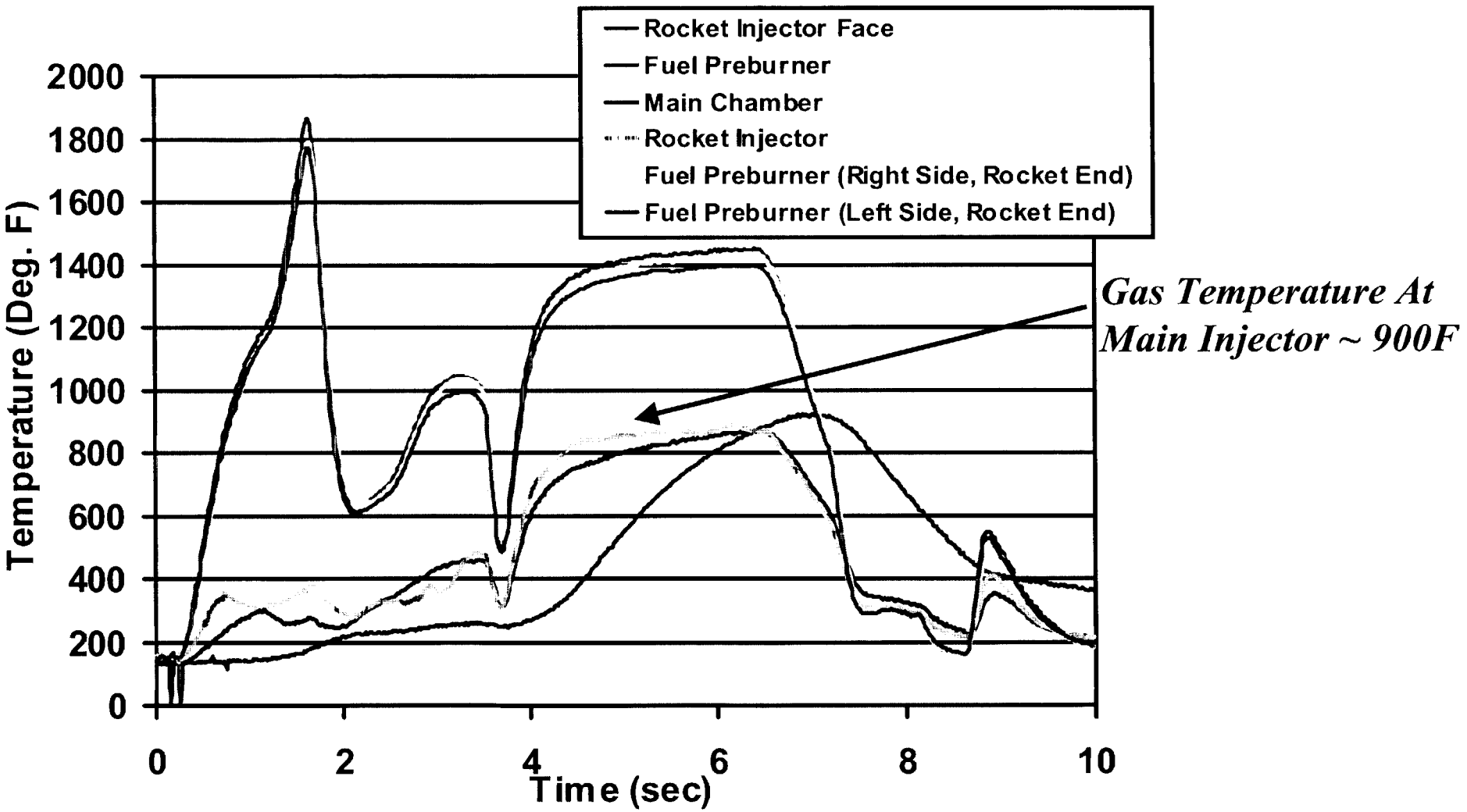
(TEMPERATURE MEASUREMENTS AT O/F=0.45)



Gas Temperature At Main Injector ~ 350 F

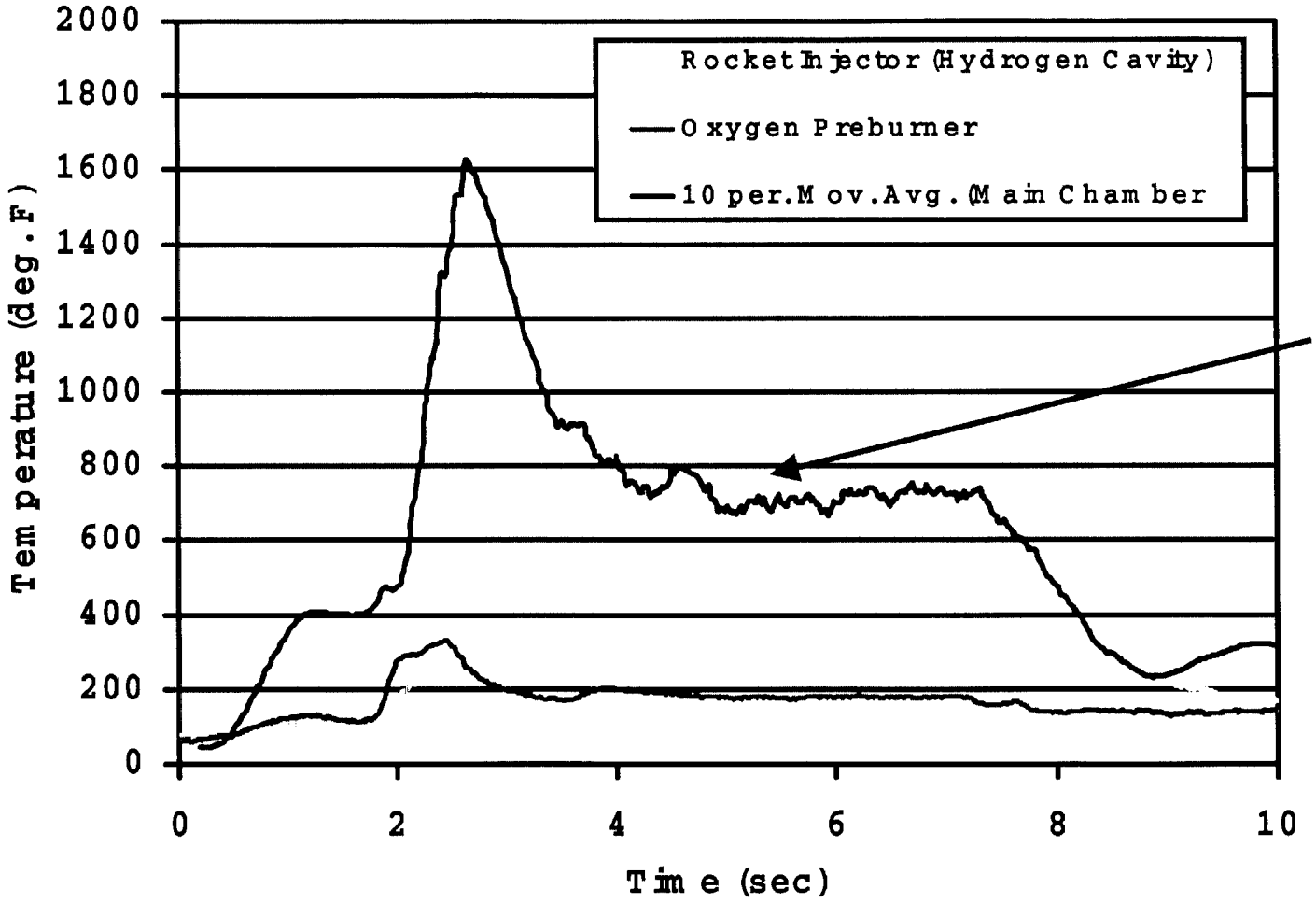
FUEL PREBURNER ONLY

(TEMPERATURE MEASUREMENTS AT O/F=1.12)



OXIDIZER PREBURNER ONLY

(TEMPERATURE MEASUREMENTS AT O/F=165)



Gas Temperature At Main Injector ~ 700F

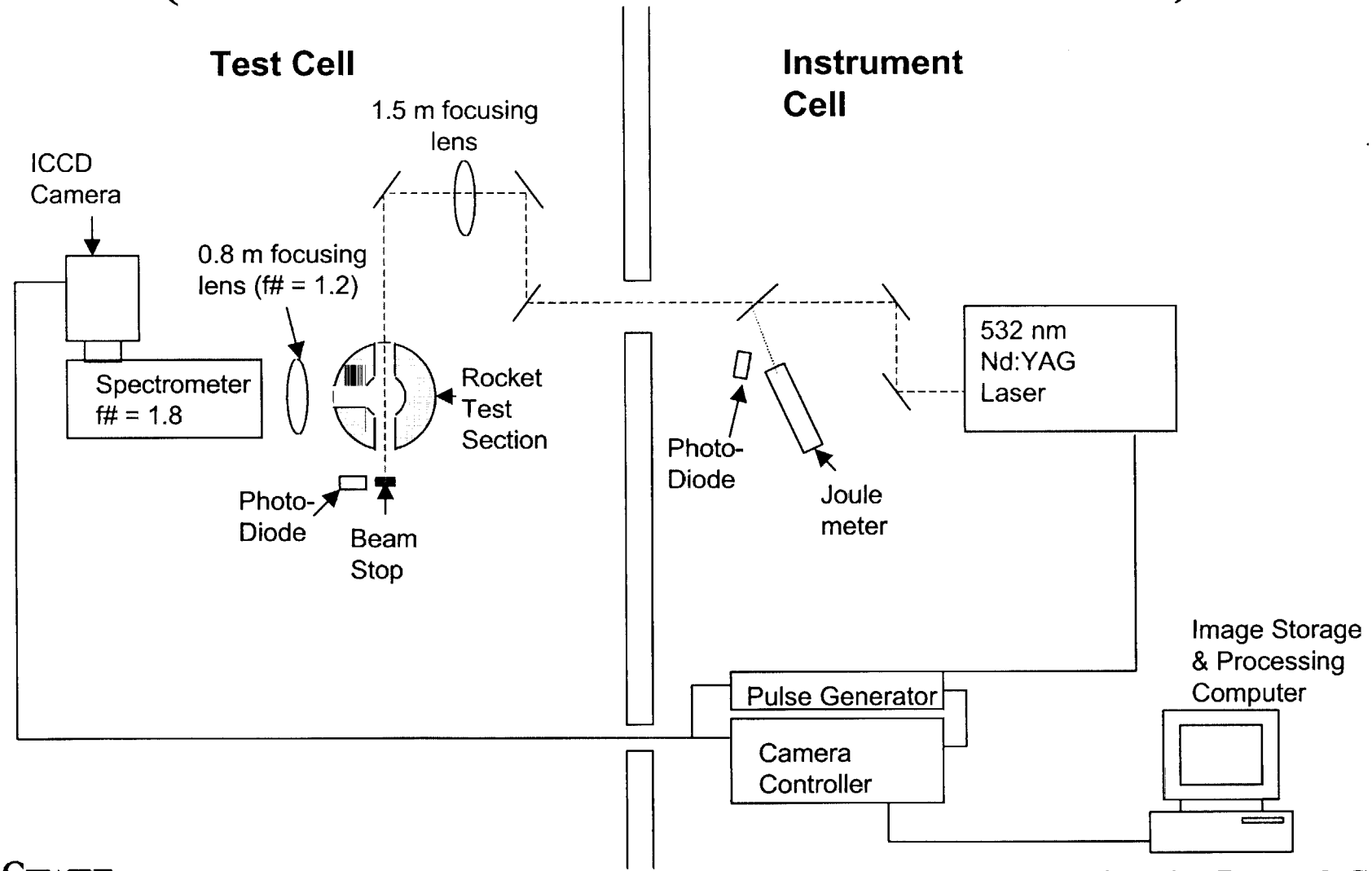
REVISED FLOW CONDITIONS

	Initial Flow Conditions	Revised Flow Conditions
Preburner Propellants	GO_2/GH_2	GO_2/GH_2
Main Chamber Pressure (psia)	750	750
# of Injection Elements	1	1
Injector Element Geometry	FULL-SCALE	FULL-SCALE
Total flowrate per Element (lbm/s)	0.295	0.322
Ox. Preburner O/F	GO_2/GH_2 and H_2O**	GO_2/GH_2 at O/F=165
Ox. Preburner Temperature (°F)	~400 (measured)	~700 (measured)
Fuel Preburner O/F	0.45	1.12
Fuel Preburner Temperature (°F)	~350 (measured)	~900 (measured)
Injection Velocity	*SAME*	*SAME*
Ox. Preburner/Fuel Preburner Flowrate Ratio	4.0	2.733
Total O_2/Total H_2	6.0	6.65

RAMAN SPECTROSCOPY SETUP (SPECTROMETER APPROACH)

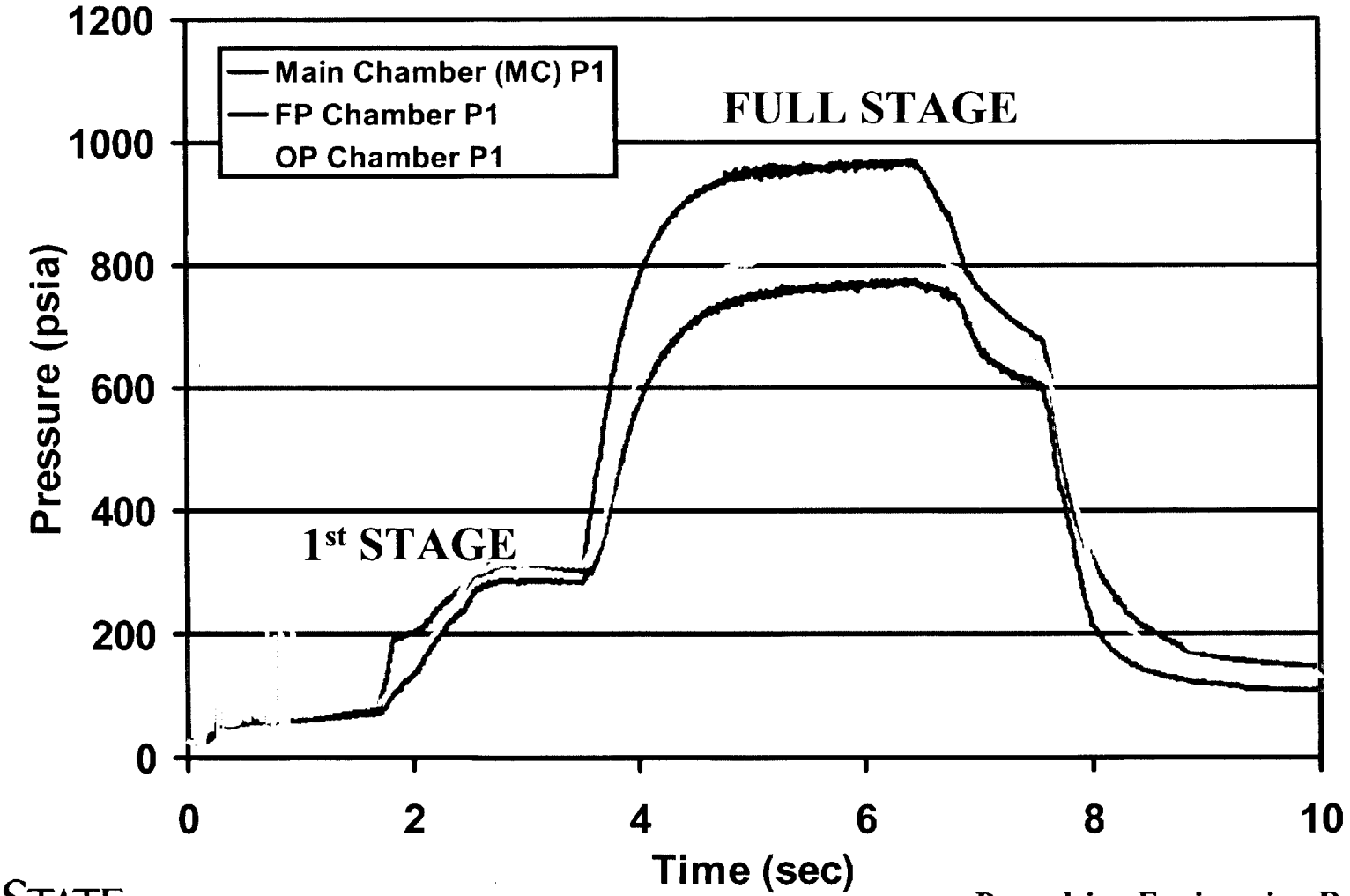
- Allows Single Shot Collection of All Major Species
- Allows Shot-to-shot Comparison of Species Concentrations
- Reduces Ambiguity Regarding Hydrogen Rotational Interference With Oxygen Signal

RAMAN SPECTROSCOPY SETUP (SPECTROMETER APPROACH)



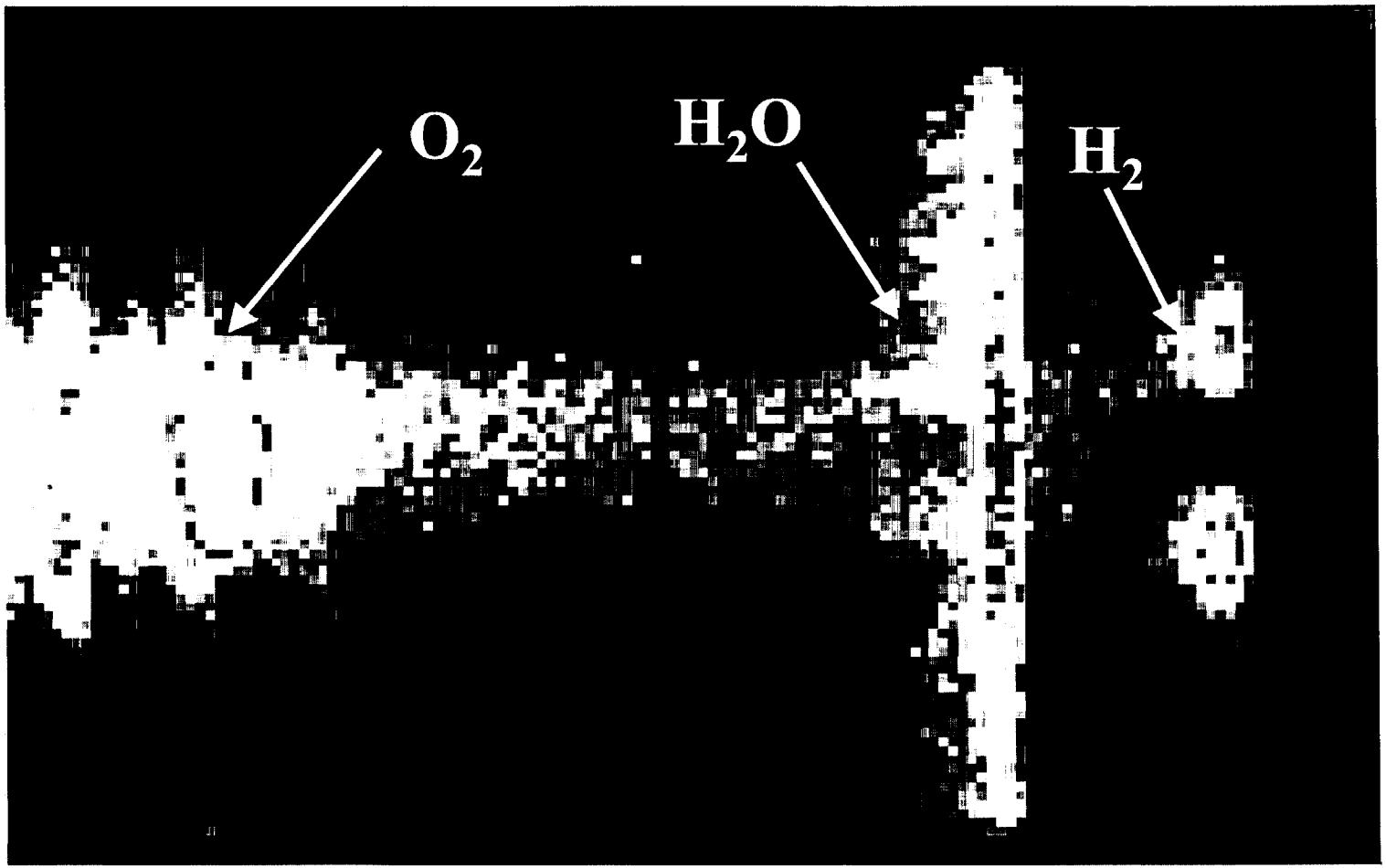
PRESSURE PROFILE FOR FULL FIRING

(SHEAR COAXIAL INJECTOR, F.P. O/F=1.12, O.P. O/F=165)



RAMAN MEASUREMENTS

(SHEAR COAXIAL INJECTOR; 0.5 in. AXIAL DISTANCE)



SPECIES MEASUREMENTS

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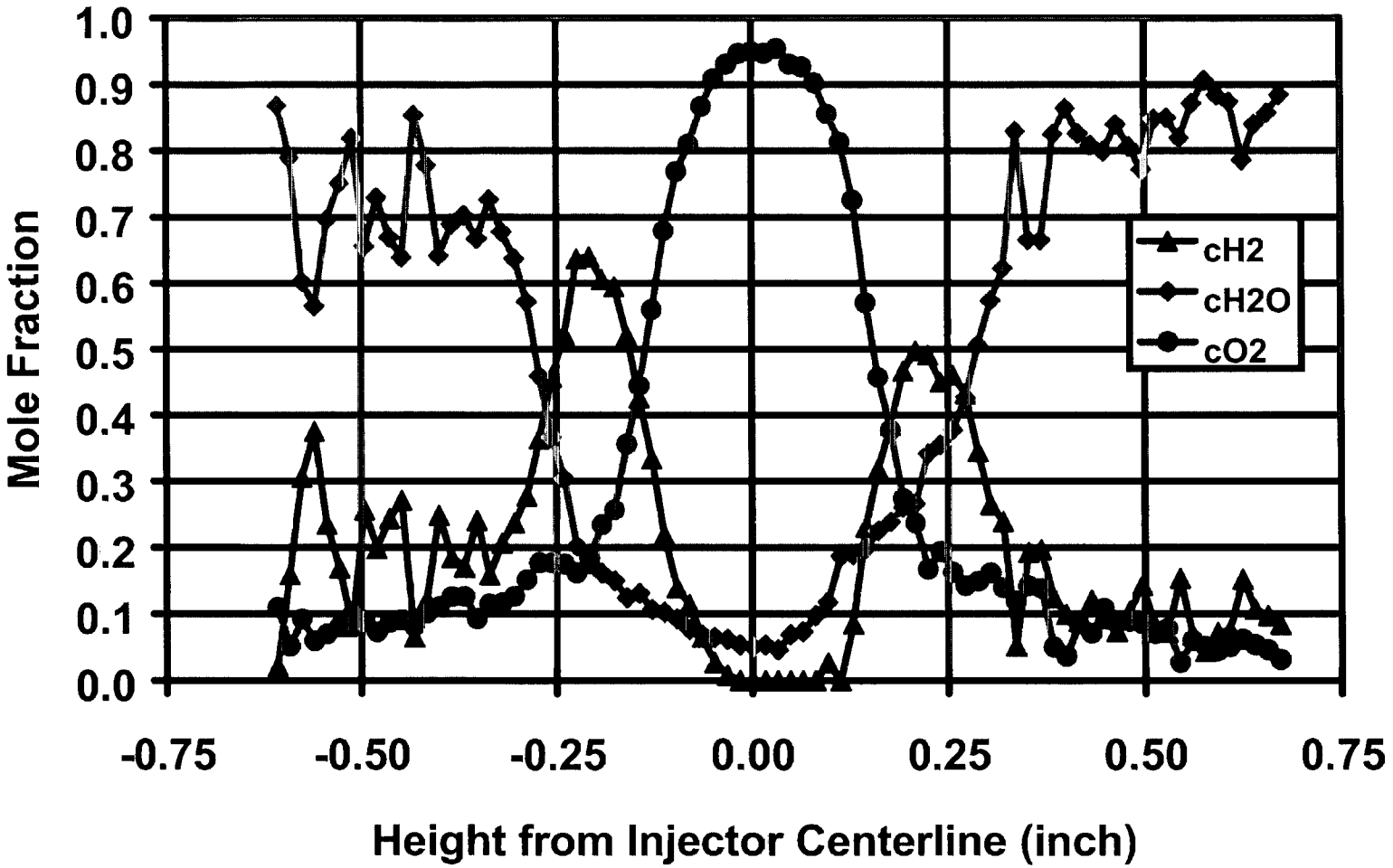

TEMPERATURE MEASUREMENTS

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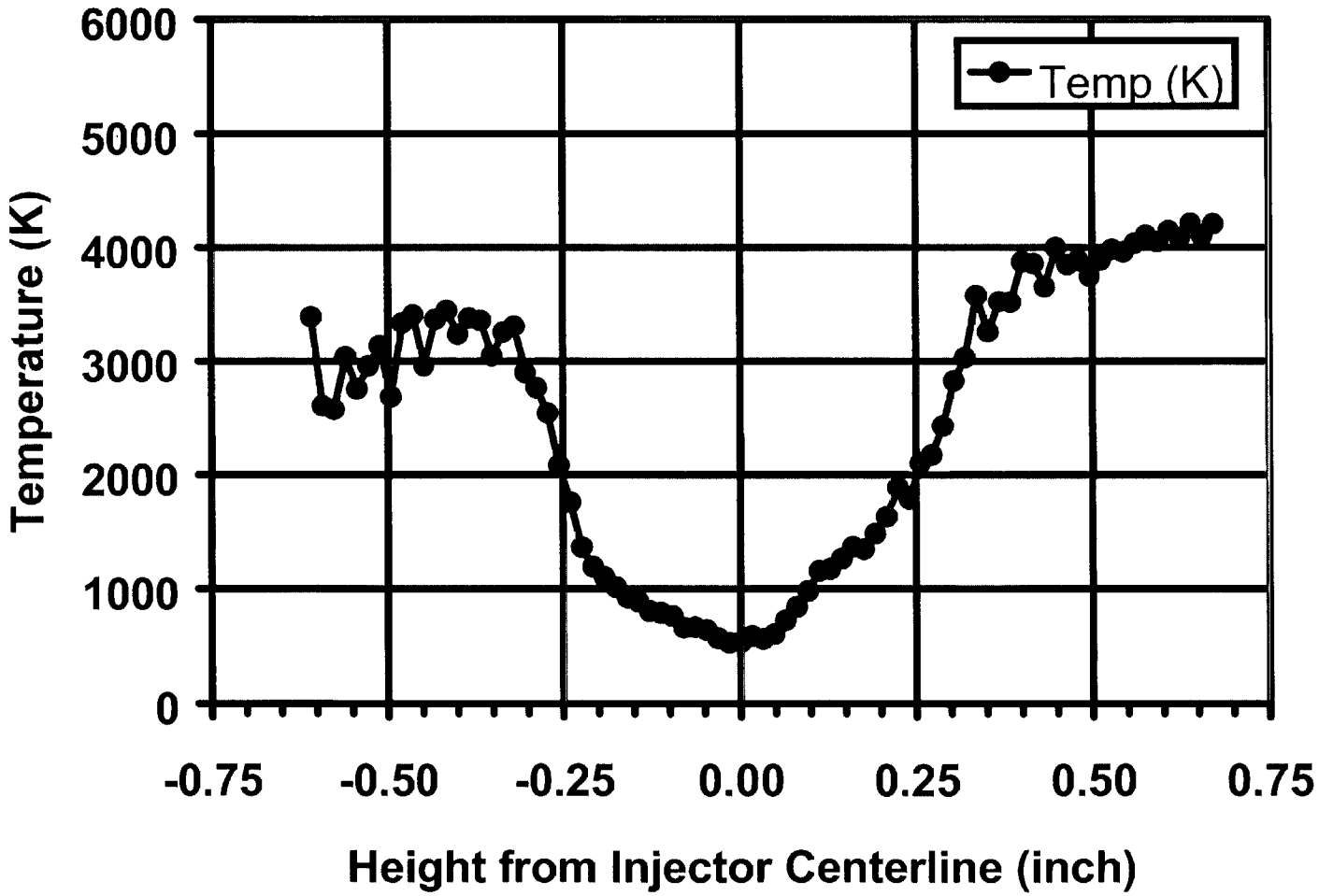

SUMMARY

- **Experimental Testbed For Uni-element Gas/Gas Injector Studies At Realistic Conditions Has Been Fabricated and Verified**
- **Experiments for Characterizing Mixing/Combustion of Gas/Gas Injectors With Raman Spectroscopy Has Been Initiated**

ACKNOWLEDGEMENTS

- Funding From NASA Marshall Space Flight Center Under NASA Contract/Grant NAG8-1792 Is Acknowledged
- The Authors Thank Mr. Larry Schaaf For Help In Conducting The Experiments
- The Authors Thank Mr. Kevin Tucker From NASA MSFC and Dr. Shahram Farhangi From Boeing Rocketdyne For Supporting The Experimental Program